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Optical absorption of an asymmetric quantum dot in the presence of an uniform magnetic field

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ABSTRACT

We theoretically investigate the optical absorption coefficient (OAC) of an asymmetric quantum dot (QD) in the presence of an uniform magnetic field. Using the effective-mass approximation, we study the electronic structure of the QD. We obtain the linear, nonlinear and total OAC by the compact-density-matrix approach and iterative method. The results of numerical calculations for the typical GaAs/AlGaAs QD show that the OAC depend strongly on the radius of the QD, parameters of the asymmetric potential, external magnetic field and incident optical intensity. Moreover, the peak of the OAC shifts with the magnetic field or the radius of the QD changing.

1. Introduction

With the development of the molecular beam epitaxy and etching technique [1], multiform confined quantum systems, such as quantum wells, quantum well wires and quantum dots (QDs), have been fabricated. Due to the discrete energy levels (subbands) and particular optical properties, the nonlinear effects in these systems are much stronger than the bulk materials [2–17]. These particular properties lead to interesting applications in photo-electronic devices, for example, the QDs that confine electrons in all three spatial dimensions are extensively applied in cellular automata, optical memories and infrared photodetectors [18]. Yakar et al. [19] investigated the linear and nonlinear optical absorption coefficients (OACs) of spherical QD with parabolic potential and the results shown that the existence of impurity has great influence on optical absorption coefficients. Vahdani and Rezaei [20] investigated the OACs in a parabolic cylinder QD and they found that the OAC is strongly

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affected by the size of QD, optical intensity and electromagnetic field polarization. Ünlü et al. [21] studied the OAC in a quantum box with finite confining potential and found that both the incident optical intensity and the structure parameters have a great effect on the total absorption. Ungan et al. [22] investigated the effects of hydrostatic pressure and intense laser field on the OAC of a square quantum well in 2012, their results showed that the intense laser field, the hydrostatic pressure and the temperature have a significant effect on the OAC. However, the OAC in an asymmetric QD has not been researched so far. What is more, considering that the application of a magnetic field can modify the transition and optical properties of electron in QD, we study the OAC in an asymmetric QD underlying an uniform magnetic field. Our results demonstrate that the OAC in this system has good adjustability simultaneously. Therefore, this system may have some reference value for photo-electronic devices.

In this paper, we investigate the OAC for the typical GaAs/AlAGaAs QD which is confined by radial potential, asymmetrical potential and an uniform magnetic field. This paper is organized as follows. In Section 2, using the effective-mass approximation, we obtain the eigenfunctions and eigenenergies of electron states. We derive the analytical expression for OAC by means of the compact-density-matrix approach and the iterative method. In Section 3, we present the numerical results and discussions in GaAs/AlGaAs asymmetric QD. The results show that the OAC depends strongly on the incident optical intensity, the size of the QD, the static magnetic field and the parameters of the asymmetric confined potential. Finally, we give a brief summary in Section 4.

2. Model and analysis

The system we studied is that an electron moves in the QD which is confined by the radial potential of the form $\frac{1}{2}m^*\omega_0^2\rho^2$, an asymmetrical potential of the form $U_0(L/z - z/L)^2$ along z direction and a perpendicular magnetic field. Using the effective-mass approximation, the evolution equation of the system can be described as the following [23–25]

$$\frac{1}{2m^*}\left(\mathbf{P} - \frac{e}{c}\mathbf{A}\right)^2\Psi + \frac{1}{2}m^*\omega_0^2 r^2\Psi + U_0\left(\frac{L}{z} - \frac{z}{L}\right)^2\Psi = E\Psi, \tag{1}$$

where m^* is the effective mass, $\mathbf{P}$ is momentum of the electron, $\mathbf{A}$ is the vector potential of the magnetic field $\mathbf{B}$ ($\mathbf{B} = \nabla \times \mathbf{A}$, where $A_\rho = A_z = 0$, $A_\varphi = B\rho/2$), and $\omega_0 = \hbar/m^*R^2$ is the frequency of electron [26]. The Schrödinger equation in cylindrical coordinates has a form

$$-\frac{1}{2m^*}\left[\frac{1}{\rho}\frac{\partial}{\partial\rho}\left(\rho\frac{\partial}{\partial\rho}\right) + \frac{\partial^2}{\partial z^2} + \frac{1}{\rho^2}\frac{\partial^2}{\partial\varphi^2}\right]\Psi + \frac{1}{2}\omega_c\hat{l}_z\Psi + \frac{1}{8}m^*\omega_c^2\rho^2\Psi + U_0\left(\frac{L}{z} - \frac{z}{L}\right)^2\Psi$$
$$+\frac{1}{2}m^*\omega_0^2\rho^2\Psi = E\Psi, \tag{2}$$

where $\omega_c = eB/m^*c$ is the cyclotron frequency and $\hat{l}_z$ is the projection of the angular momentum onto the magnetic field direction.

The corresponding eigenfunctions of this system can be expressed as

$$\Psi = f(\rho,\varphi)\chi(z), \tag{3}$$

$$f(\rho,\varphi) = \frac{1}{a^{1+|m|}}\sqrt{\frac{(|m|+n)!}{2\pi 2^{|m|}n!}}\frac{1}{m!}\exp(im\varphi)\rho^{|m|} \times \exp\left(-\frac{\rho^2}{4a^2}\right)F\left(-n, |m|+1, \frac{\rho^2}{2a^2}\right), \tag{4}$$

$$\chi(z) = C_{n_z} z^\nu \exp\left(-\sqrt{\frac{m^*U_0}{2\hbar^2L^2}}z^2\right) \times F\left(-n_z, \nu + \frac{1}{2}, \sqrt{\frac{m^*U_0}{2\hbar^2L^2}}z^2\right), \tag{5}$$

where $a = \sqrt{\frac{\hbar}{m^*\Omega}}$ is the effective length scale, $\Omega = \sqrt{\omega_c^2 + 4\omega_0^2}$, $F(a, b, x)$ is the confluent hypergeometric function, n is the radial quantum number, m is the magnetic quantum number, C_{n_z} is the normalization constant, $\nu = \frac{1}{2}\sqrt{\frac{8m^*U_0L^2}{\hbar^2} + 1} + 1$, and n_z is the quantum number.